ESTABLISHING RADIOLOGICAL SCREENING LEVELS FOR DEFENSE-RELATED URANIUM MINE (DRUM) SITES ON BLM LAND USING A RECREATIONAL FUTURE-USE SCENARIO*

U.S. DEPARTMENT OF ENERGY | Legacy Management

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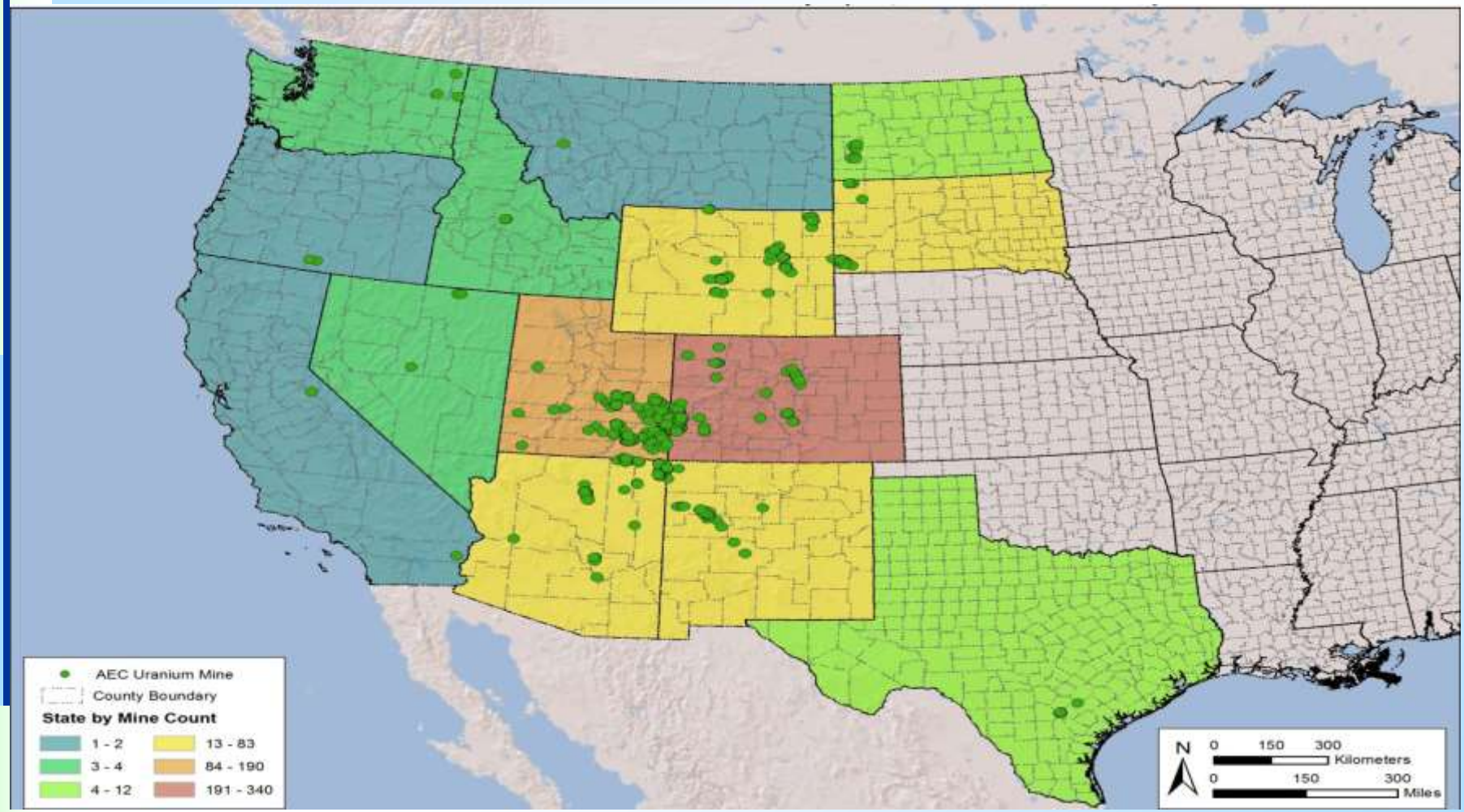
*Brown S H et al.. Journal of Health Physics. June 2018, Volume 114, Number 6

Defense Related Uranium Mining Sites (DRUM)

- DOE-LM responsible for verification and validation of over two thousand DRUM sites located on Federal land (most are small – but some not)
- Uranium ore purchased by the US Government was extracted prior to 1970 for defense programs.
- Most are in SW US, remote and semi arid (States of CO, UT, WY, AZ, NM).
- Radiological screening criteria developed and now being applied to assist in prioritizing this very large number of sites (along with physical hazards, human accessibility, etc.)

Western US – Historical Uranium Mining Districts and DRUM Sites



Typical Environments – Abandoned Uranium Mines (AUM), e.g. – DRUMs

Example DRUM Sites - continued

Campfire ring at Johns Incline,
Yellow Cat District, Utah

Wedge 1 Mine, Eagle Basin, Colorado

Ore bin, Buckshot Mine,
Club Mesa Area, Colorado

Physical Hazards

Physical hazards often dominate the risk profile of these sites:

- Decaying and unstable surface features
- Open holes and shafts
- Unstable open mine adits
- Unstable high walls and waste rock piles

Assumptions: Radiological Environment

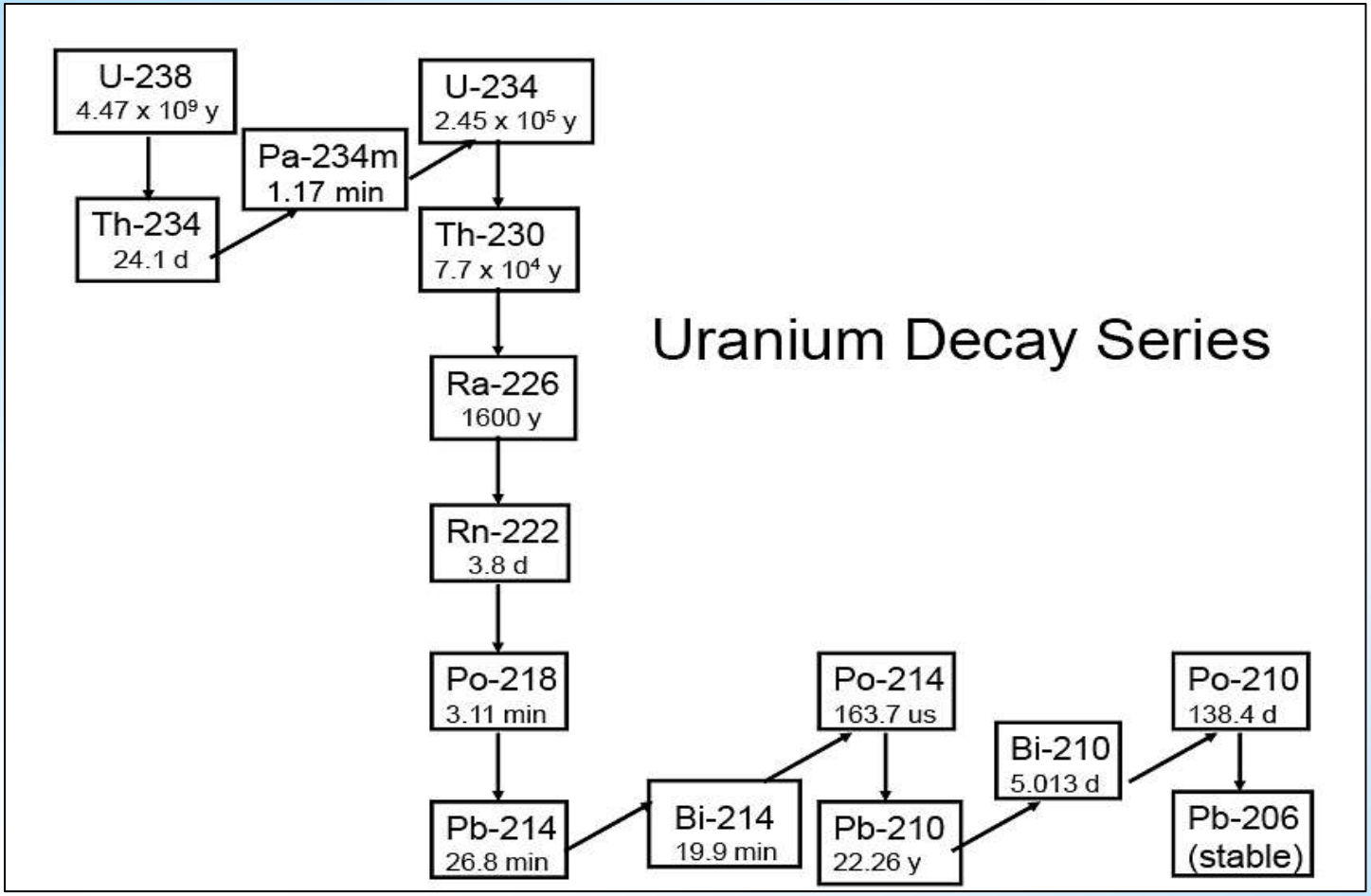
- Contaminants of Concern = natural uranium ore in soil, waste rocks and spoils piles.
- Full radioactive equilibrium in both ^{238}U and ^{235}U decay series.
- Ratio of ^{235}U activity to ^{238}U activity is the natural abundance ratio (0.046).
- Contribution from natural thorium (^{232}Th) series is negligible - consistent with general ^{232}Th regional background.

Relative Abundances of Naturally Occurring Uranium* Isotopes

Isotope	Percent of Mass in U Natural	Percent of Radioactivity in U Natural	Half Life (years)
^{238}U	99.3	48.9	4.5 billion
^{235}U	0.72	2.2	704 million
^{234}U	0.005	48.9	245,000

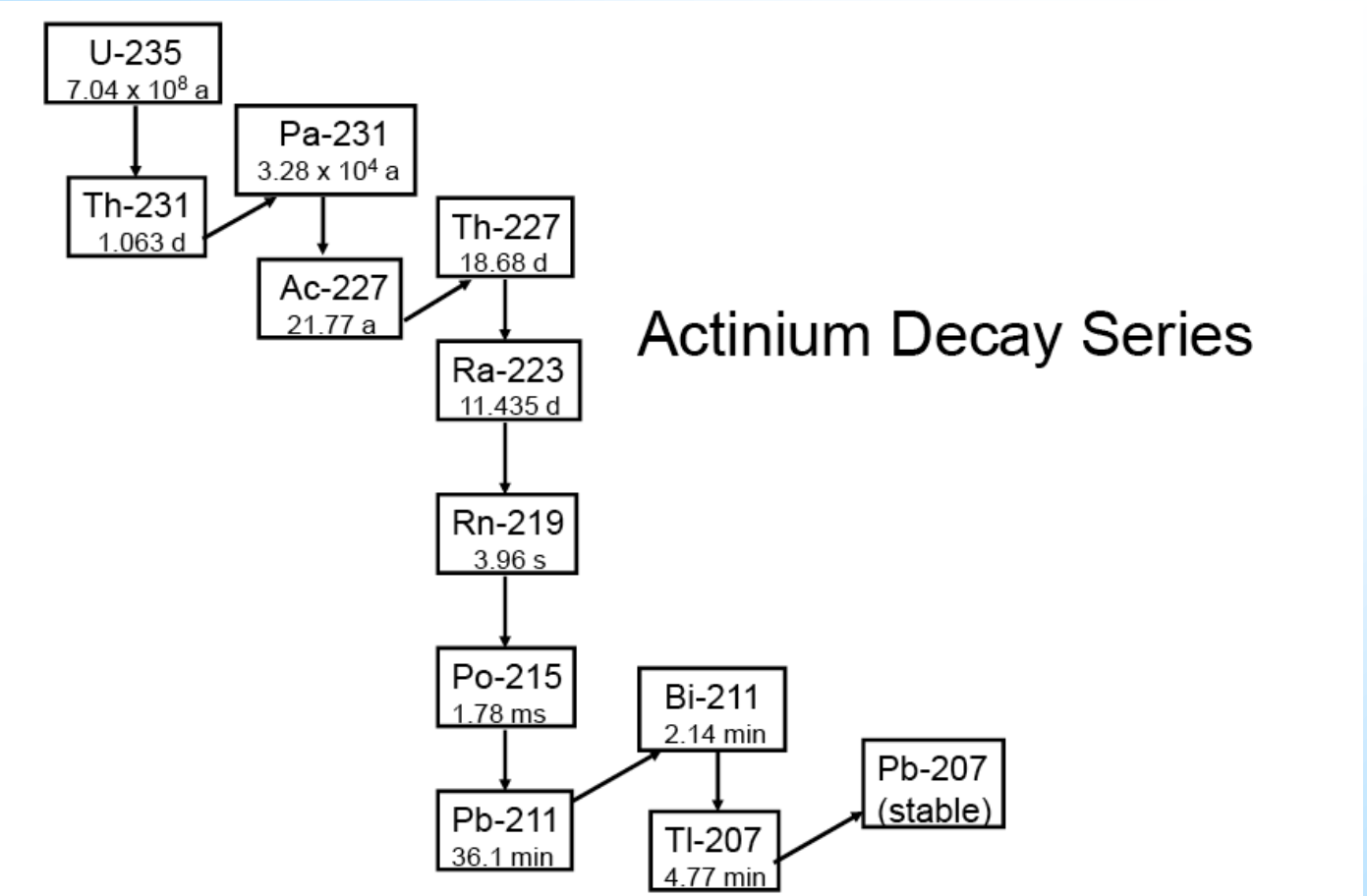
*U.S. Public Health Service, Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Uranium*. 2011.

Uranium Series Radiological Source Term



From Oak Ridge Institute for Science and Education (ORISE). 2011.

Uranium Series Radiological Source Term - continued

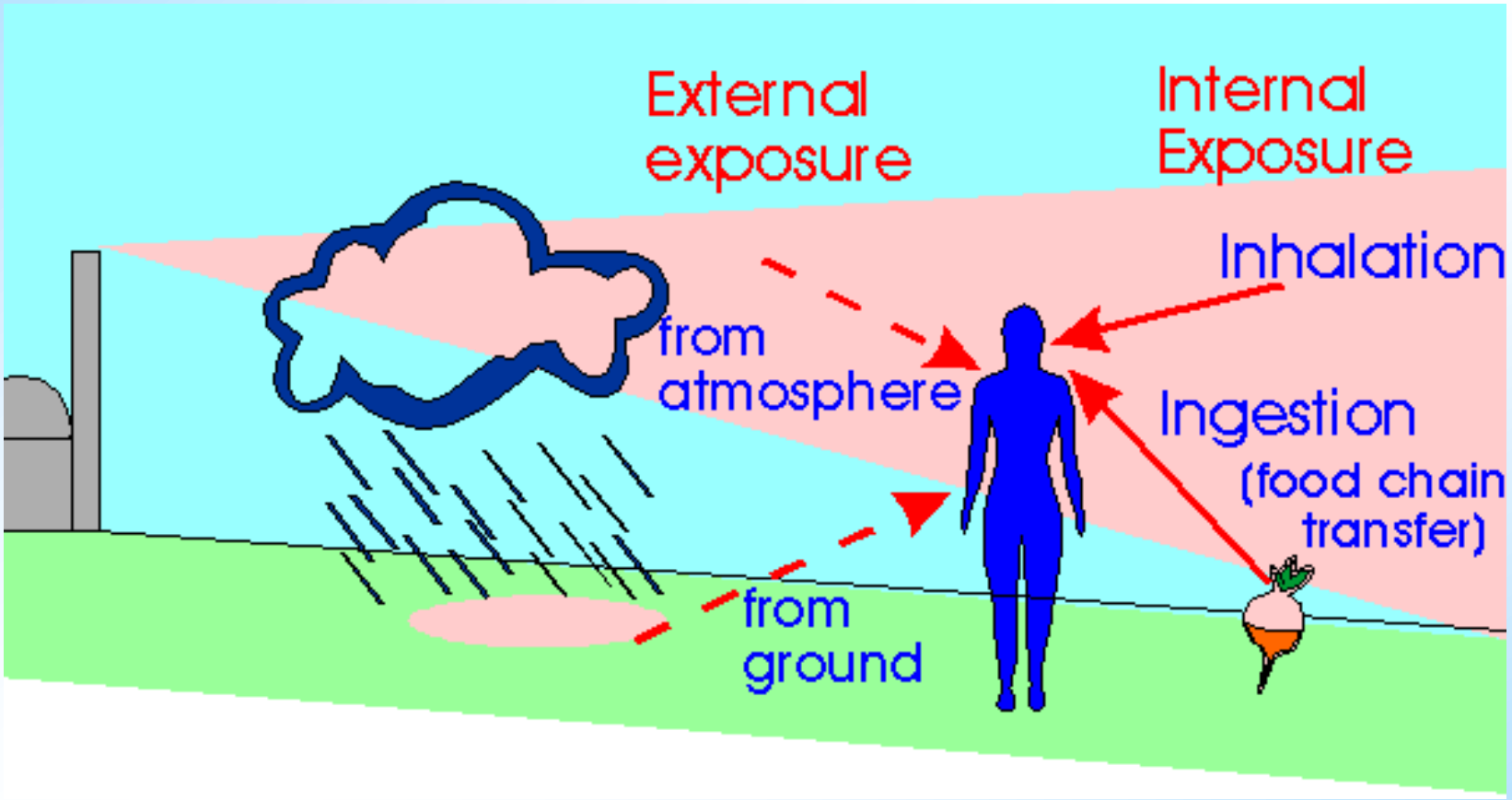


From Oak Ridge Institute for Science and Education (ORISE). 2011.

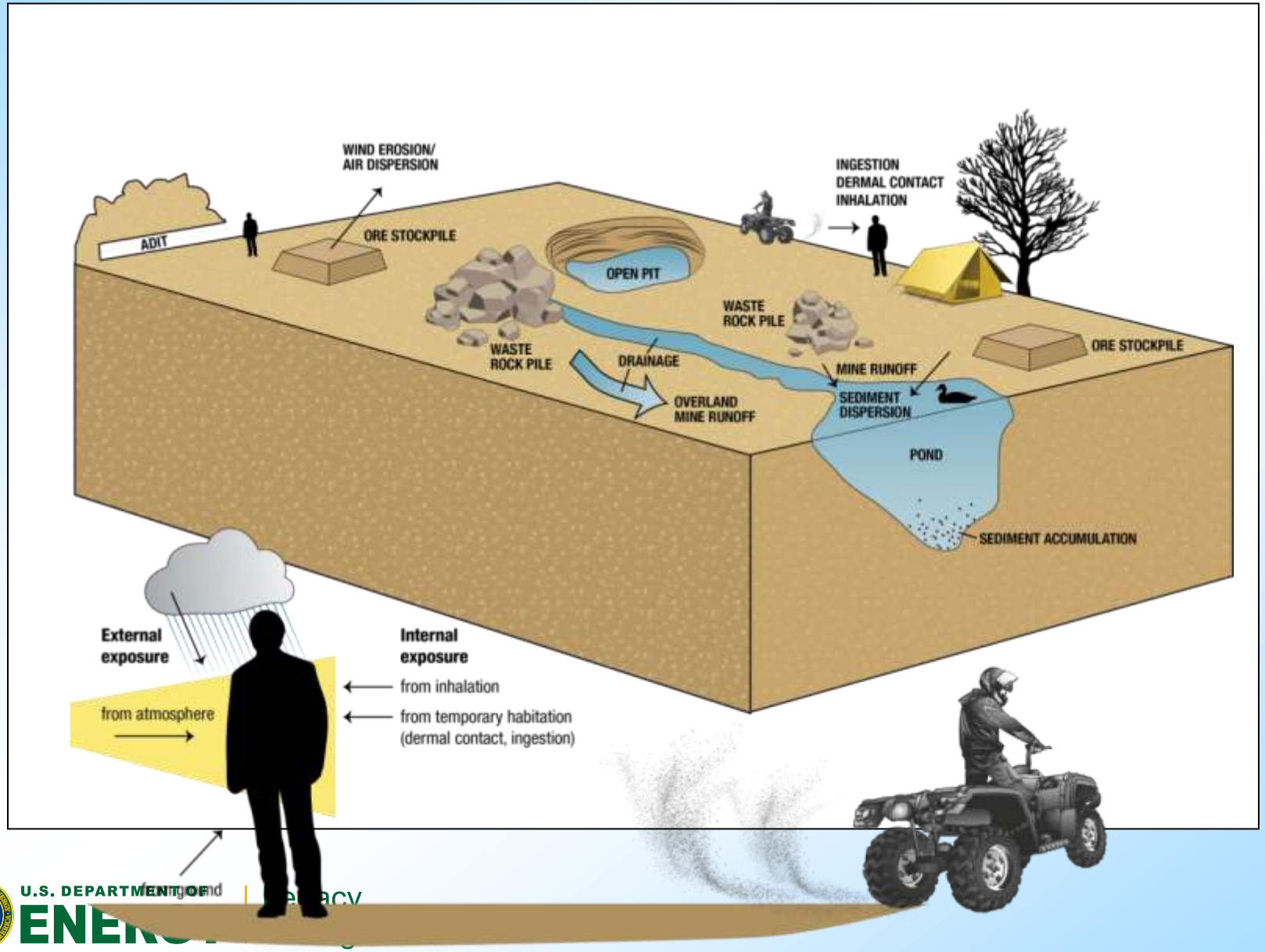
Typical Radiological Composition – Ore Residues

- U ore grade defines the percent uranium in ore and is therefore a measure of its radioactivity concentration
- Typical uranium ores mined in the Colorado Plateau (Four Corners area of Colorado, New Mexico, Utah, and Arizona) during 1950s and 60s were a few percent uranium by mass (higher-grade 4–5%)
- For grade of 1% uranium (10,000 ppm), the ^{238}U activity alone would be about 120 Bq / gram (3300 pCi / gram)
- So assuming residues / spoils / waste rock left behind (protore) about 0.1 – 0.2 % U = 12 - 25 Bq / gram (350 – 700 pCi / gram) of each U series progeny in secular equilibrium with ^{238}U parent (+ 13 progeny)

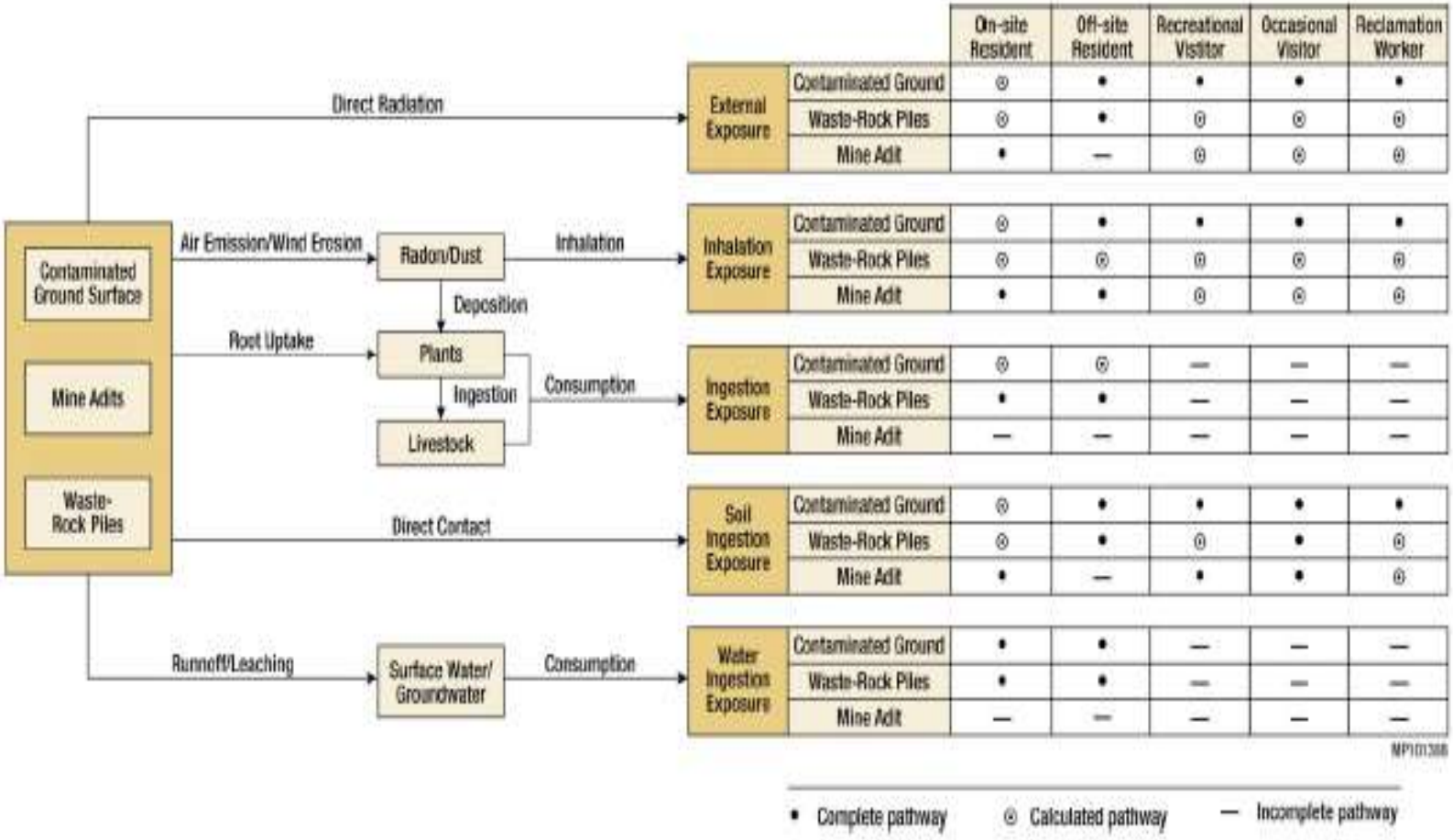
Generalized Pathways of Exposure



Conceptual Site Model # 1 – DOE DRUM Sites



Conceptual Site Model #2 – DOE DRUM Sites



		On-site Resident	Off-site Resident	Recreational Visitor	Occasional Visitor	Reclamation Worker
External Exposure	Contaminated Ground	⊛	•	•	•	•
	Waste-Rock Piles	⊛	•	⊛	⊛	⊛
	Mine Adit	•	—	⊛	⊛	⊛
Inhalation Exposure	Contaminated Ground	⊛	•	•	•	•
	Waste-Rock Piles	⊛	⊛	⊛	⊛	⊛
	Mine Adit	•	•	⊛	⊛	⊛
Ingestion Exposure	Contaminated Ground	⊛	⊛	—	—	—
	Waste-Rock Piles	•	•	—	—	—
	Mine Adit	—	—	—	—	—
Soil Ingestion Exposure	Contaminated Ground	⊛	•	•	•	•
	Waste-Rock Piles	⊛	•	⊛	•	⊛
	Mine Adit	•	—	•	•	⊛
Water Ingestion Exposure	Contaminated Ground	•	•	—	—	—
	Waste-Rock Piles	•	•	—	—	—
	Mine Adit	—	—	—	—	—

• Complete pathway ⊛ Calculated pathway — Incomplete pathway

Applicable Exposure Scenario = Recreational

- Sites are generally remote and semi arid - essentially water independent.
- Deep groundwater; some sites have small creeks and streams in vicinity.
- Vegetation sparse - game animals migratory
- Full time resident farmers and ranchers not realistic.
- Camper spends 2 weeks / year at site engaged in recreational activities (permits on Federal land limited to 2 weeks / yr.)*

*As defined by US BLM

Recreational Scenario Defined –Applicable Exposure Pathways

- External exposure from the soil, i.e. ground shine.
- Casual ingestion of Uranium ore in soil.
- Inhalation of Uranium ore in dusts.
- Inhalation of radon gas and particulate progeny.
- No traditional ingestion pathways - no native vegetables.
- Special case of dust inhalation for an Off-Highway Vehicle (OHV) rider.
- Camper may hunt or fish and eat catch, but due to general lack of forage vegetation, animals would be transitory / migratory through the area.

Pathway Comparison

Factor/Condition of Exposure	DOE/BLM Recreational Scenario	Traditional Subsistence Farmer/Rancher
1. Annual exposure period	14 days (336 hrs.)	Full time (365 days/yr..)
2. Food ingestion pathways	Not credible: must bring own food, vegetation sparse, migratory game animals	Invoked and may use agronomic and related food product production and dietary consumption rates not representative of geographic region
3. Water ingestion	Must bring own water	Assumes domestic water supply from local well in contaminated zone
4. Radon/ progeny pathway	Minor contribution to dose: little ingrowth of particulate progeny from fresh radon; outdoor concentrations beyond short distance from source(s) are at background level	Residency (farmhouse) usually assumed for 25 to 50 percent of the year; progeny concentrations 50 percent equilibrium or higher
5. Annual exposure limit	1.0 mSv	0.12 mSv per year (CERCLA law); 0.25 / 1.0 mSv per year above background per NRC

Acceptable Public Exposure Limit

- DOE public exposure limit for nuclear facilities is 100 mrem/yr.
- 2007 International Commission on Radiation Protection (ICRP) 103 recommendation is 1 mSv (100 mrem)/yr.
- In the United States, agencies apply differing limits based on types of sites and/or circumstances
  - NRC annual public exposure limits:
    - 100 mrem/yr. for licensed nuclear facilities
    - 25 mrem/yr. for decontamination and decommissioning (D&D) and license termination (10 CFR 20.1402)
  - EPA annual limits:
    - 12 mrem/yr. for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites

Natural Background Levels Can Vary Considerably Across the US (mrem / yr.)

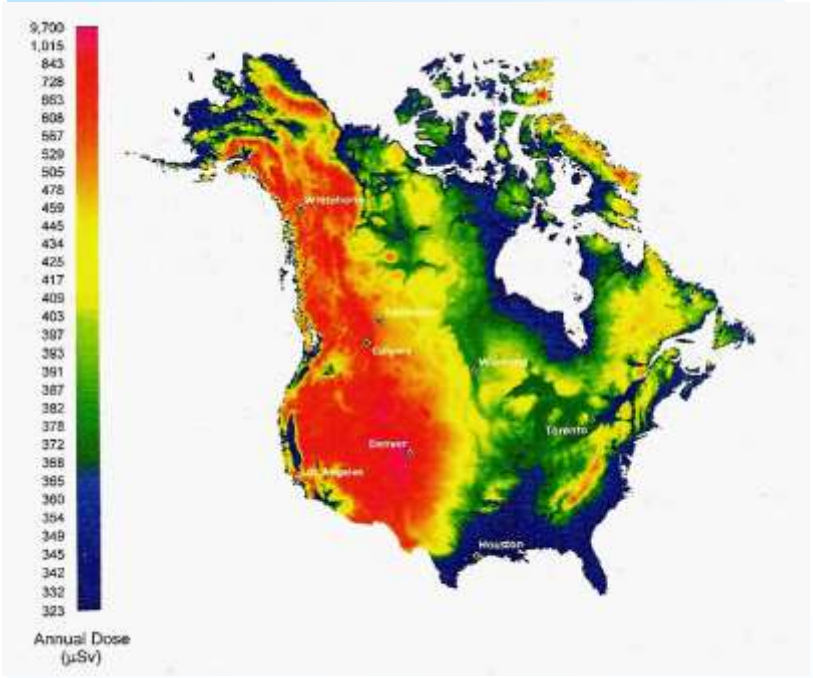
Source	U.S Avg. (NCRP, 2009)	Colorado Avg. (EPA, 2005)	Leadville (Moeller, 2006)
Cosmic Radiation	28	47	85
Terrestrial Radiation	28	43	97
Internal Radiation including Radon	200	610	344
Totals	256	700	526

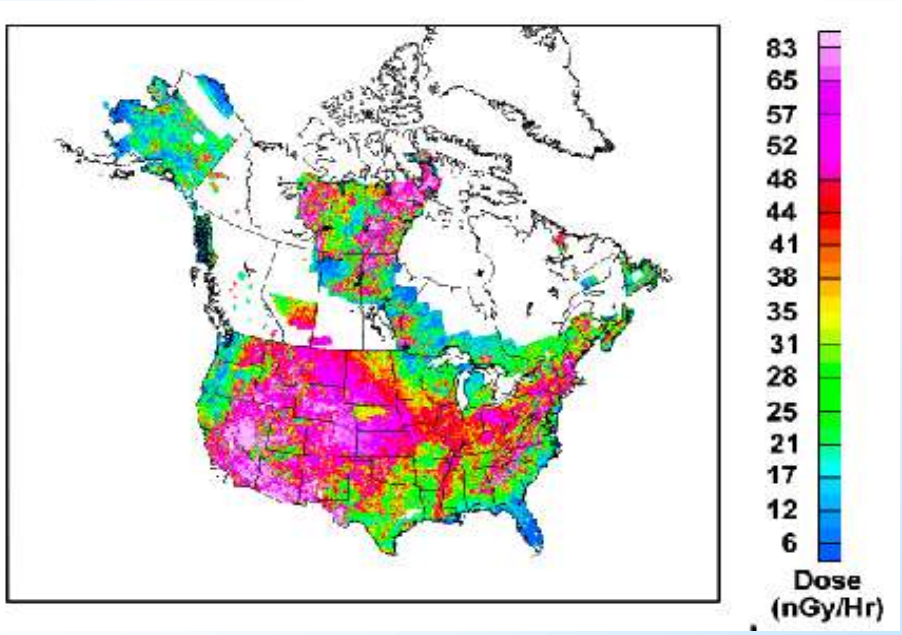
*NCRP 2009: National Council on Radiation Protection and Measurements. Ionizing radiation exposure of the population of the United States. NCRP Report No. 160

EPA 2005:US Environmental Protection Agency. Assessment of variations in radiation exposure in the United States.

Moeller D, Sun LSC. Comparison of natural background dose rates for residents of the Amargosa Valley, NV, to those in Leadville, CO, and the states of Colorado and Nevada. Health Phys 91:338-353; 2006.

Cosmic Ray and Terrestrial Background Varies Considerably Across US





National Council on Radiation Protection and Measurements; NCRP Report No. 160, "Ionizing Radiation Exposure of the Population of the United States", 2006

Methodology – Developing Radiological Screening Levels

- "Put" a unit concentration of the reference radionuclide(s) – e.g., 1 Bq/gram of 238U - "in the soil" along with the associated ratios of the other dosimetrically important radionuclides (all 1 Bg/gram since secular equilibrium)
- Using appropriate intake, transport and dose assessment models (acceptable to the regulator), perform intake / fate / transport and dose modeling to establish the annual dose associated with the reference nuclide and mixture in each relevant pathway and sum results.
- This defines the "reference dose" per unit concentration in the soil. A simple ratio of the dose limit to the reference dose defines the concentration in soil and/or hourly exposure rate that ensures the dose limit will not be exceeded.

Methodology - Continued

"Put" unit concentration of 238U in soil - e.g., 1 Bq/gram; all other nuclides in decay series = 1 Bq/gram (equilibrium)*

$$T = Ex + S_{inj} + I_d + I_{ohv} + I_{Rn}$$

T = Total Effective Dose Equivalent (TEDE) for a 14 day recreational exposure scenario per Bq/gram of each of the 238 U plus 235 U series radionuclides in soil (1 Bq = 27 pCi).

Ex = Dose Equivalent (DE) from external exposure from the soil

S_{inj} = Committed Effective Dose Equivalent (CEDE) from incidental ingestion of soil

I_d = CEDE from inhalation of dusts

I_{ohv} = CEDE from inhalation of dusts during use of OHV

I_{Rn} = CEDE from inhalation of 222 Rn and progeny

* Approach also described in IAEA 2011. Exposure of the Public from Large Deposits of Mineral Residues IAEA-TECDOC-1660

External Dose Conversion Factor

- From Table 5.1 of NCRP Publication No. 94*
  - Absorbed dose rate in air from 1 pCi/g in soil of ^{238}U + daughters is 139 microgrey (uGy)/yr
  - Using conversions therein from absorbed dose (tissue) to exposure rate in air is essentially equivalent to 1.8 uR/hr

*NCRP 1987. National Council on Radiation Protection and Measurements. *Exposure of the Population of the United States and Canada from Natural Background Radiation*. NCRP Report 94.

Casual Ingestion of Soil – Ingestion Dose Conversion Factors – Sv / Bq intake

Sv = 100 Rem = 10,000 mrem; Bq = 27 pCi

Radionuclide	DCF from USEPA 1988	DCF from ICRP No. 68 (1994a) and/or ICRP No. 78 (1997)
238U	6.9E-8	4.4E-8
235U	7.2E-8	4.6E-8
234U	7.6E-8	4.9E-8
234Th	3.7E-9	3.4E-9
230Th	1.5E-7	2.1E-7
226Ra	3.6E-7	2.8E-7
210Po	5.1E-7	2.4E-7
210Pb	1.4E-6	6.8E-7
Aggregate DCF	**2.6 E-6**	**1.6 E-6**

Actinide (235 U) decay series has been ignored since the ratio of 235U activity to 238U activity in uranium ore dust is the natural abundance ratio of 0.046 to 1 and contributions to the aggregate ingestion DCF are small. Some radionuclides in the 238U decay series have also been ignored since their DCFs are < E-9 Sv / Bq

Inhalation of Ore Dusts – Inhalation Dose Conversion Factors – Sv / Bq intake

Series	Radionuclide	Type	Type of emitter	Inhalation dose coeff's. (5 um AMAD) (Sv/Bq)	Specific Activity (Bq/g)	Effective 5 um inhalation dose coeff's. (Sv/αBq)
URANIUM	Uranium-238	S	α	5.7E-06	1.00	5.7E-06
	Thorium-234	S	β	5.8E-09	1.00	5.8E-09
	Protactinium-234m		β	0.0E+00	1.00	0.0E+00
	Uranium-234	S	α	6.8E-06	1.00	6.8E-06
	Thorium-230	S	α	7.2E-06	1.00	7.2E-06
	Radium-226	M	α	2.2E-06	1.00	2.2E-06
	Radon-222		α	0.0E+00	1.00	0.0E+00
	Polonium-218		α	0.0E+00	1.00	0.0E+00
	Lead-214	F	β	4.8E-09	1.00	4.8E-09
	Bismuth-214	M	β	2.1E-08	1.00	2.1E-08
	Polonium-214		α	0.0E+00	1.00	0.0E+00
	Lead-210	F	β	1.1E-06	1.00	1.1E-06
	Bismuth-210	M	β	6.0E-08	1.00	6.0E-08
	Polonium-210	M	α	2.2E-06	1.00	2.2E-06
ACTINIUM	Uranium-235	S	α	6.1E-06	0.046	2.8E-07
	Thorium-231	S	β	4.0E-10	0.046	1.8E-11
	Protactinium-231	S	α	1.7E-05	0.046	7.8E-07
	Actinium-227	S	β	4.7E-05	0.046	2.2E-06
	Thorium-227	S	α	7.6E-06	0.046	3.5E-07
	Radium-223	M	α	5.7E-06	0.046	2.6E-07
	Radon-219		α	0.0E+00	0.046	0.0E+00
	Polonium-215		α	0.0E+00	0.046	0.0E+00
	Lead-211	F	β	5.6E-09	0.046	2.6E-10
	Bismuth-211		α	0.0E+00	0.046	0.0E+00
	Thalium-207		β	0.0E+00	0.046	0.0E+00
	Gross alpha activity concentration (αBq/g)				8.322	2.9E-05
	Weighted dose conversion coefficient (alpha only) (mSv/Bq)					0.00350
	Weighted dose conversion coefficient (alpha only) (Sv/Bq)					3.500E-06

IAEA 2004.Occupational Radiation Protection in the Mining and Processing of Raw Materials; No. RS-G-1.6. Annex: *Relationships Between Gross Alpha Activity and Committed Effective Dose For The Inhalation of Ore Dust Containing Uranium or Thorium*

Examples of Other Input Parameters that Needed to Evaluated

- Particulate Emission Factor (PEF) – to estimate dust concentration in air (m3 / kg)*
- Soil Ingestion Rates (mg/day) – vary adults vs. children*
- Breathing Rates (m3/day) - vary for different activities*
- Equilibrium Factor – Radon Progeny / Fresh Radon **

* From EPA 2008 ; ** From NRC 1980

Results

$TEDE = Ex + S_{inj} + I_d + I_{ohv +} I_{Rn}$

T = 168 + 2.8 + E-3 + 0.3 + 19.6 = 191 uSv (0.19 mSv per Bq /g

1 mSv / 0.19 mSv per Bq/g = 5.3 Bq/gram at 1 mSv per yr.

Contribution to the TEDE from external gamma exposure = 168 / 191 = 88%

This relationship is used directly to establish an average gamma exposure rate above background that ensures < “annual limit” (e.g., 1mSv) during 2 weeks per year of recreational use (camping, etc.)

Results: Bottom Line – The Screening Levels

To ensure ≤ 100 mrem / year under the Recreational Exposure Scenario:

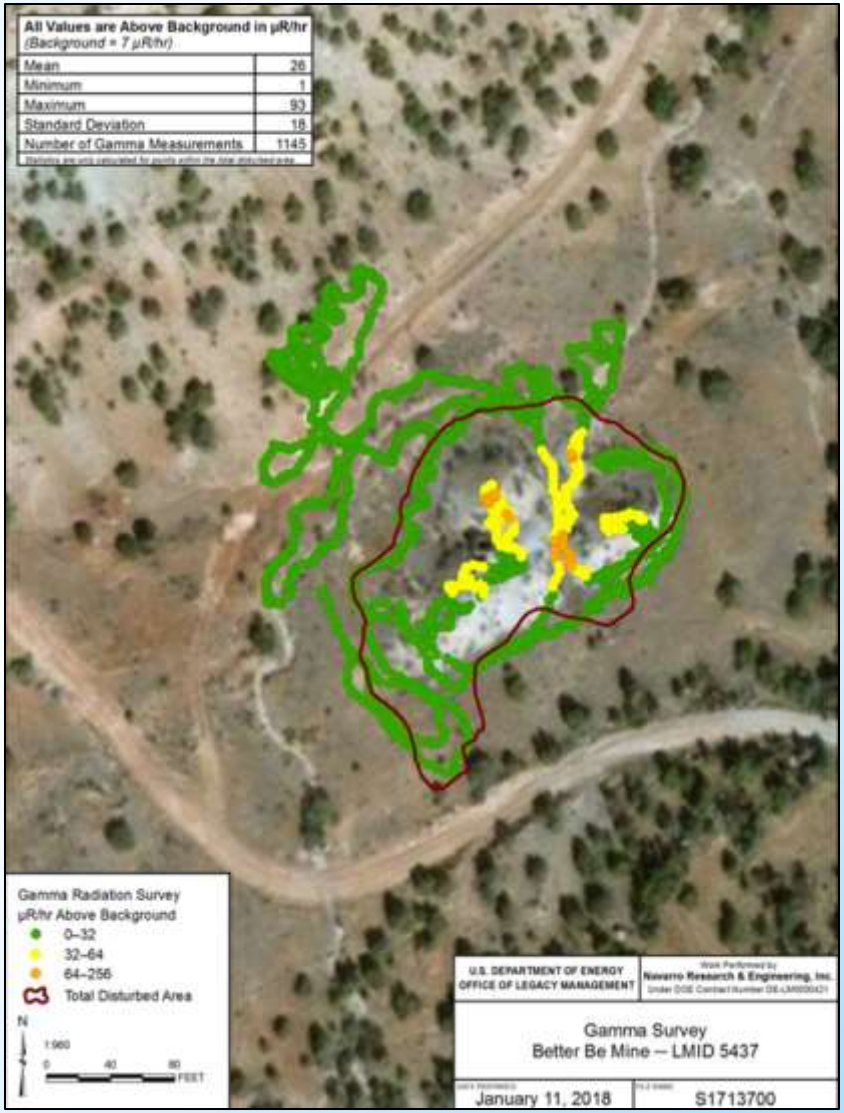
Exposure rate of about 256 µrem per hour which equates to a Radium 226 concentration in soil = 147 pCi per gram

Also: Gamma Survey Results > 25% of criteria (256 / 4) = 64 µrem per hour) also noted on survey maps*

*Equivalent to 25 mrem / year for unrestricted release per USNRC License Termination Rule (10 CFR 20, Subpart E)

Gamma Surveys Used for Comparison to Screening Levels

- Uses a backpack-mounted gamma detector with GPS
- Provides real-time data
- Utilizes color-coding to represent range of elevated gamma
- Covers mine site and drainages, which are then bounded by background
- Uses 20-30 foot (6-9 meters) spacing of transects
- Many areas are not accessible due to steep terrain



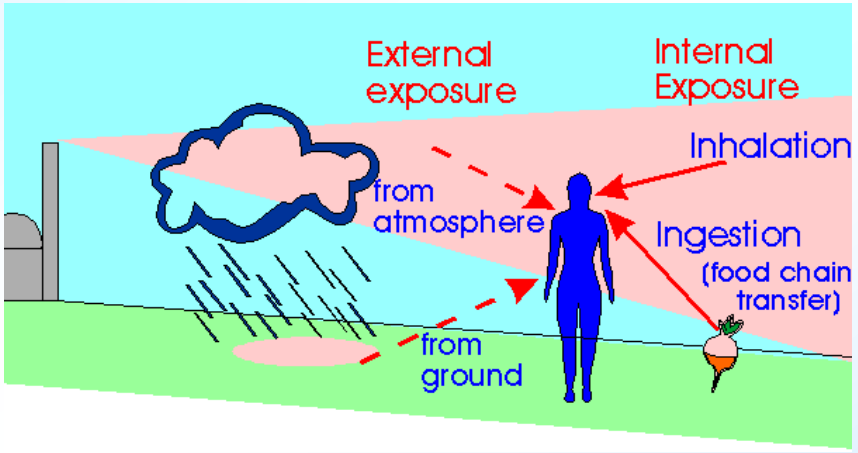
Conclusions

- Used 2-weeks per year for a recreational camper with associated exposure pathways
- Consistent with limitations of use established by BLM and U.S. Forest Service for the climate and ecosystems associated with these generally remote and semi-arid sites
- Exposure pathways included
  - Inhalation and ingestion of dusts and soil
  - Radon and progeny inhalation
  - Gamma exposure from soil
- Key objective: determine gamma exposure rate for screening purposes as input to overall hazard assessment to be used for setting priorities

Conclusions (continued)

- Objective accomplished via taking advantage of secular equilibrium of Uranium ore to define source term, calculating doses for each pathway per unit concentration of natural Uranium (+ progeny) in soil and summing
- Gamma exposure pathway dominates the dose under the recreational exposure scenario (>85 percent) and can be readily measured in the field
- Accordingly, it provides direct empirical data to calculate associated ^{226}Ra concentrations in the soil which is the standard criteria used by other federal agencies for establishing unrestricted use objectives for legacy Uranium sites
- Over 300 DRUM sites surveyed to date using these criteria

Questions?



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